



Jet Propulsion Laboratory
California Institute of Technology

Panel: Mars Exploration Science in the Next Decade

Mars Science Beyond Sample Return

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Pre-decisional: For planning and discussion purposes only

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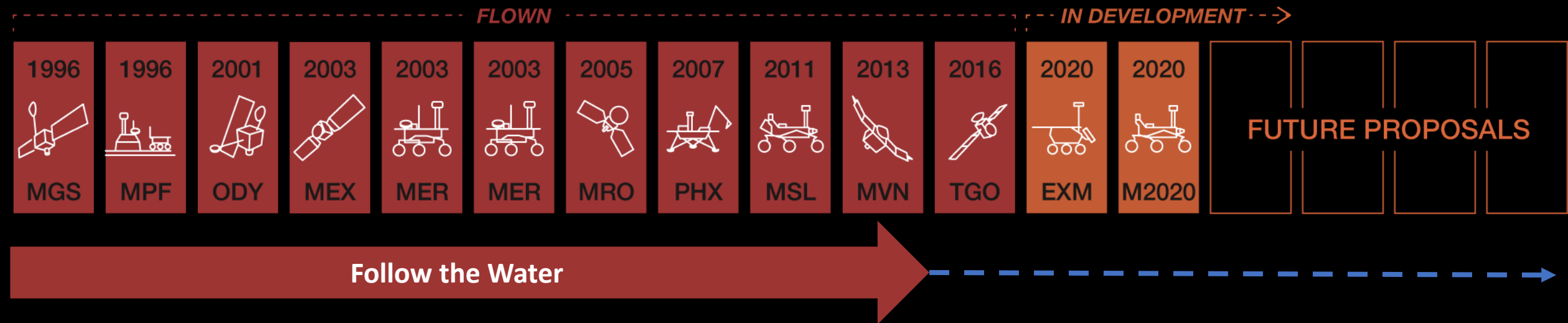


Mars exploration would not
end with Mars sample return.

What's next?

Follow the science...

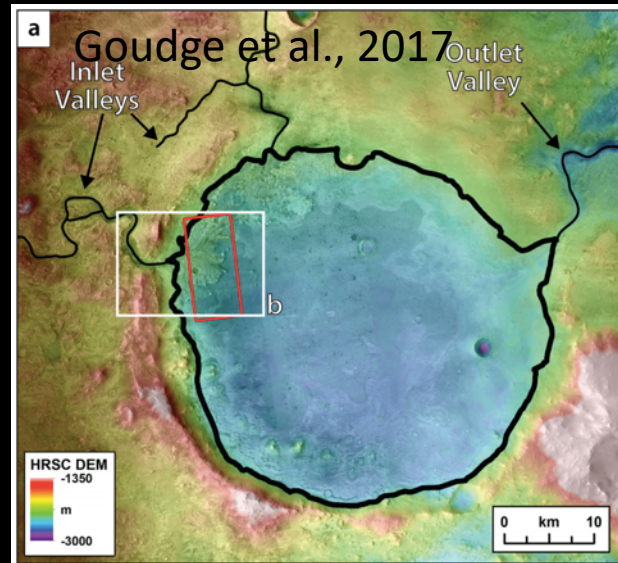
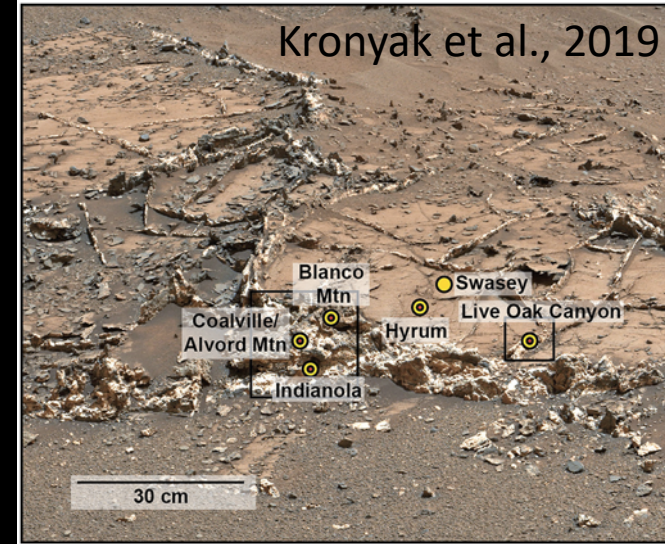
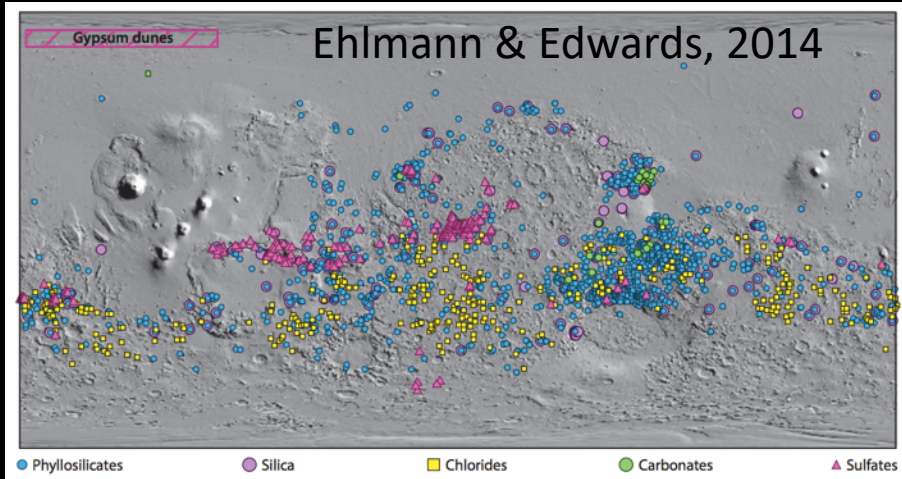
Evolving Science Strategies for Mars Exploration



Yes, we found Mars supported liquid water in the surface and subsurface!

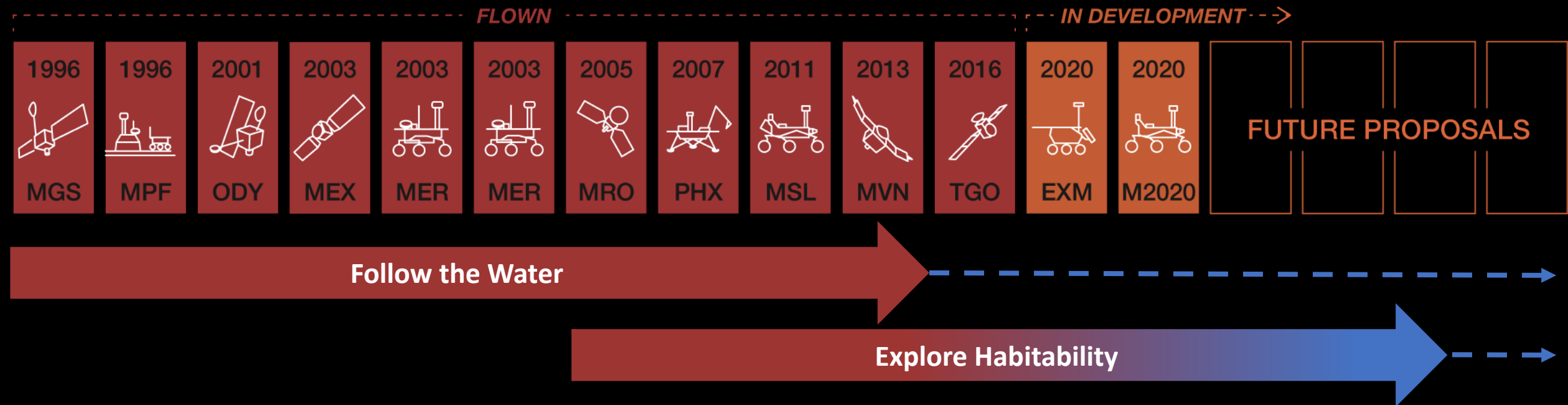
Kilometers
Orbiters, global

Micrometers
Landers/Rovers, local



Squyres et al., 2004

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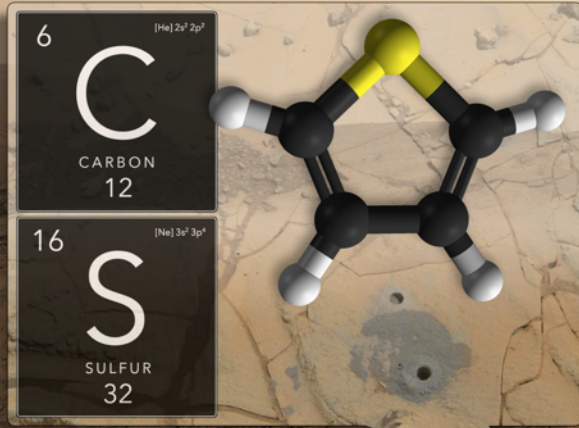


Many kinds of past habitats on Mars

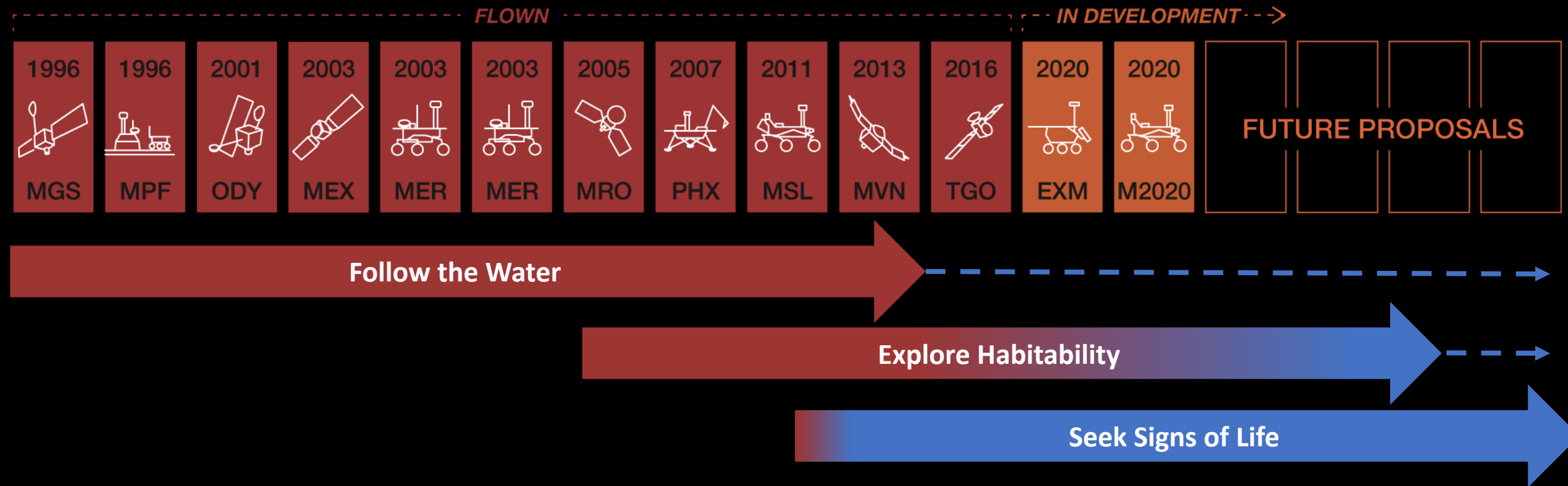
Discovered by orbiters and landers



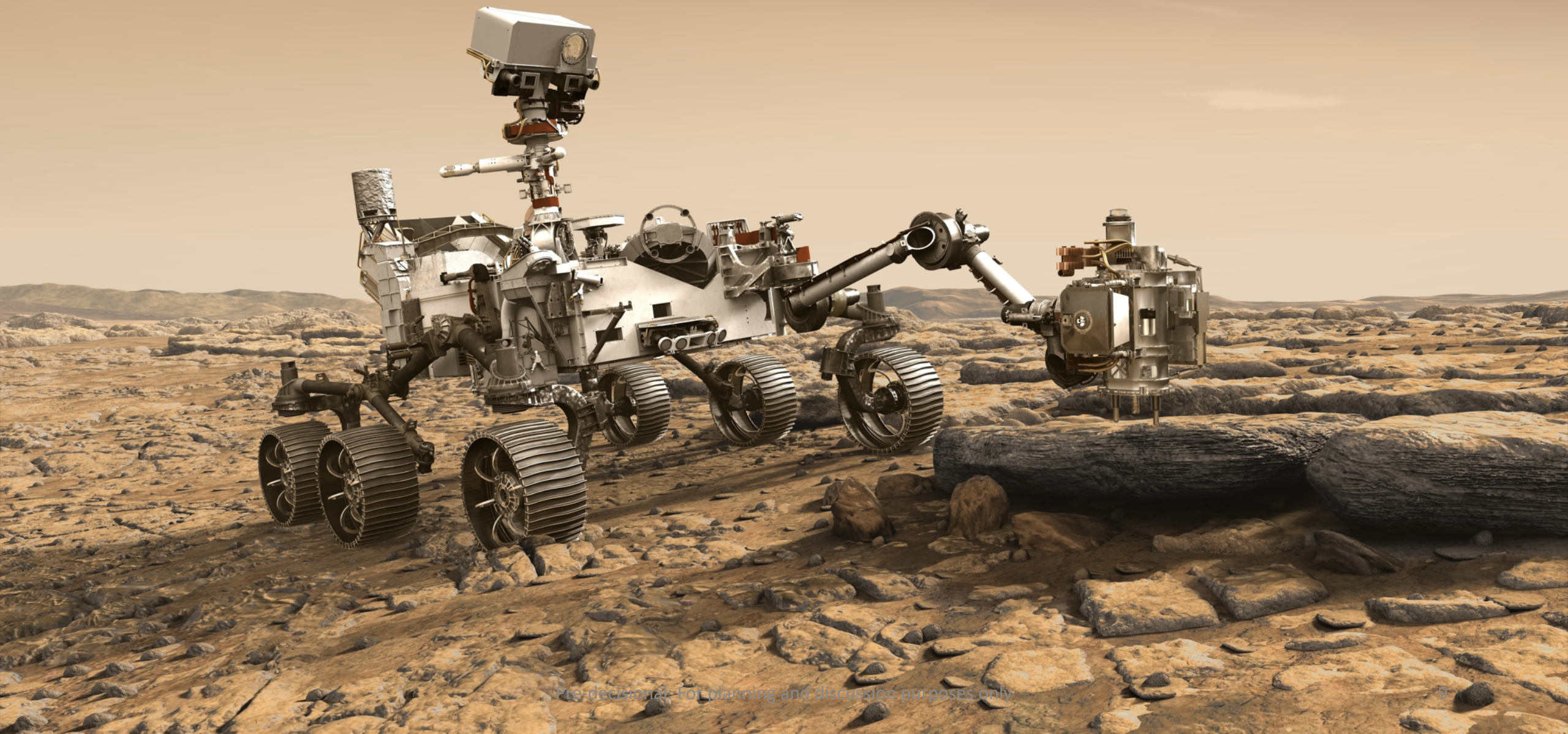
Gale Crater: Found past habitable environment + building blocks of life

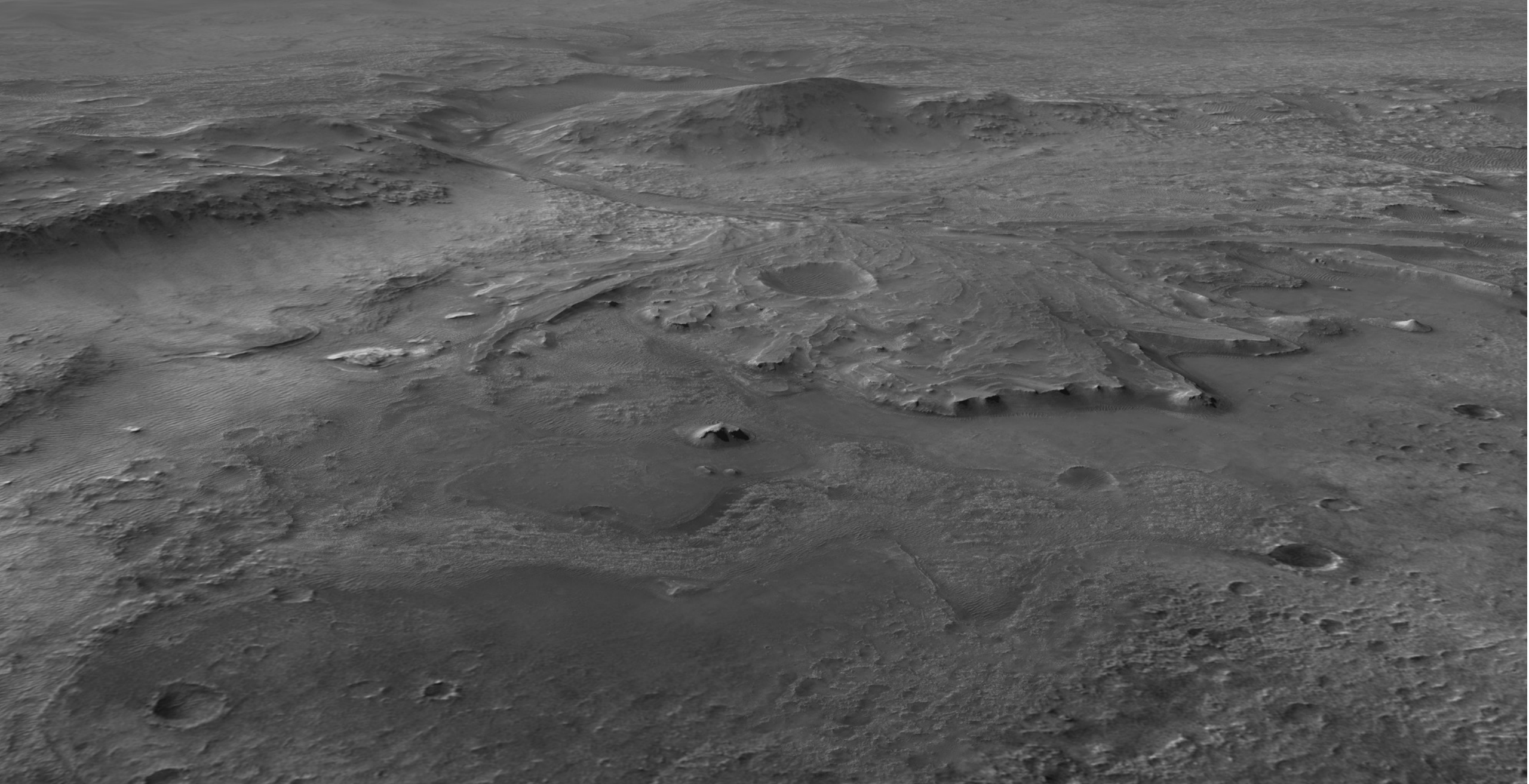


Evolving Science Strategies for Mars Exploration



Was there life on Mars?





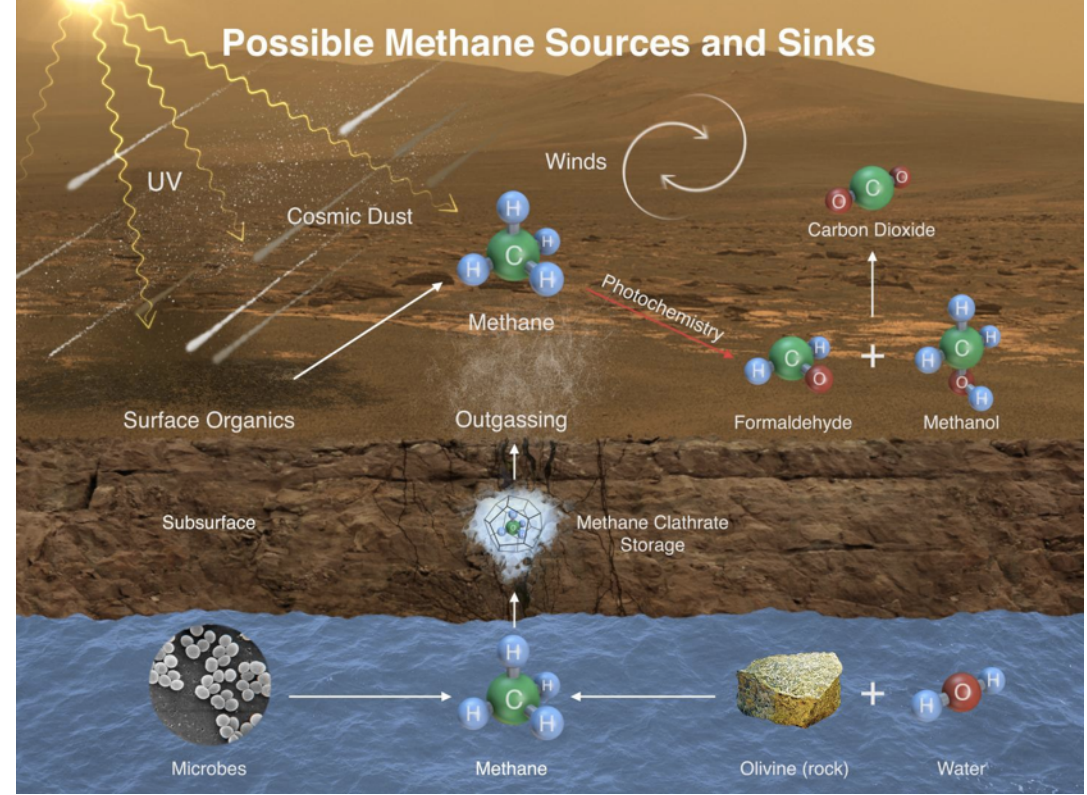
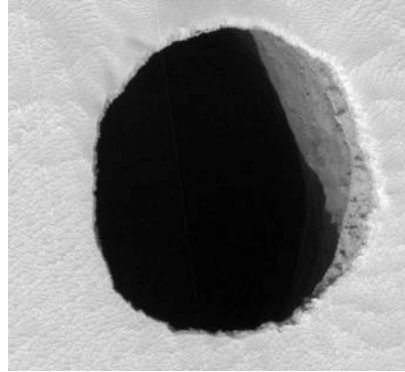
Jezero Crater, perspective view from HiRISE data.
Image credit: NASA / JPL / UA / Seán Doran

Is there life on Mars?

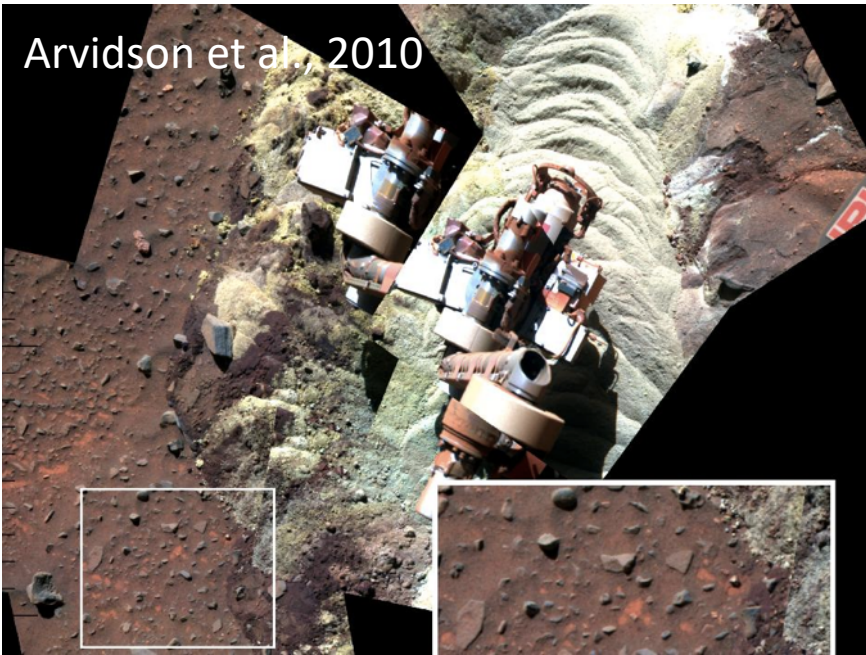
McEwen et al., 2014



Cushing et al., 2007



Arvidson et al., 2010



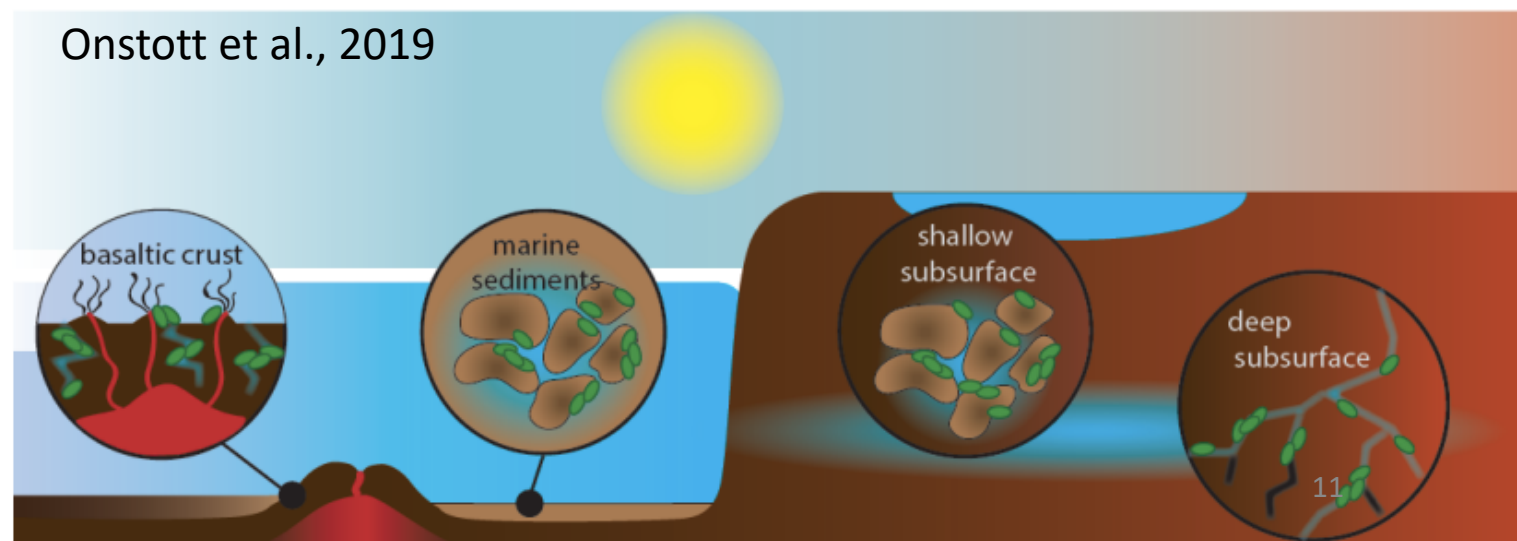
Webster et al., 2018

Icy Worlds

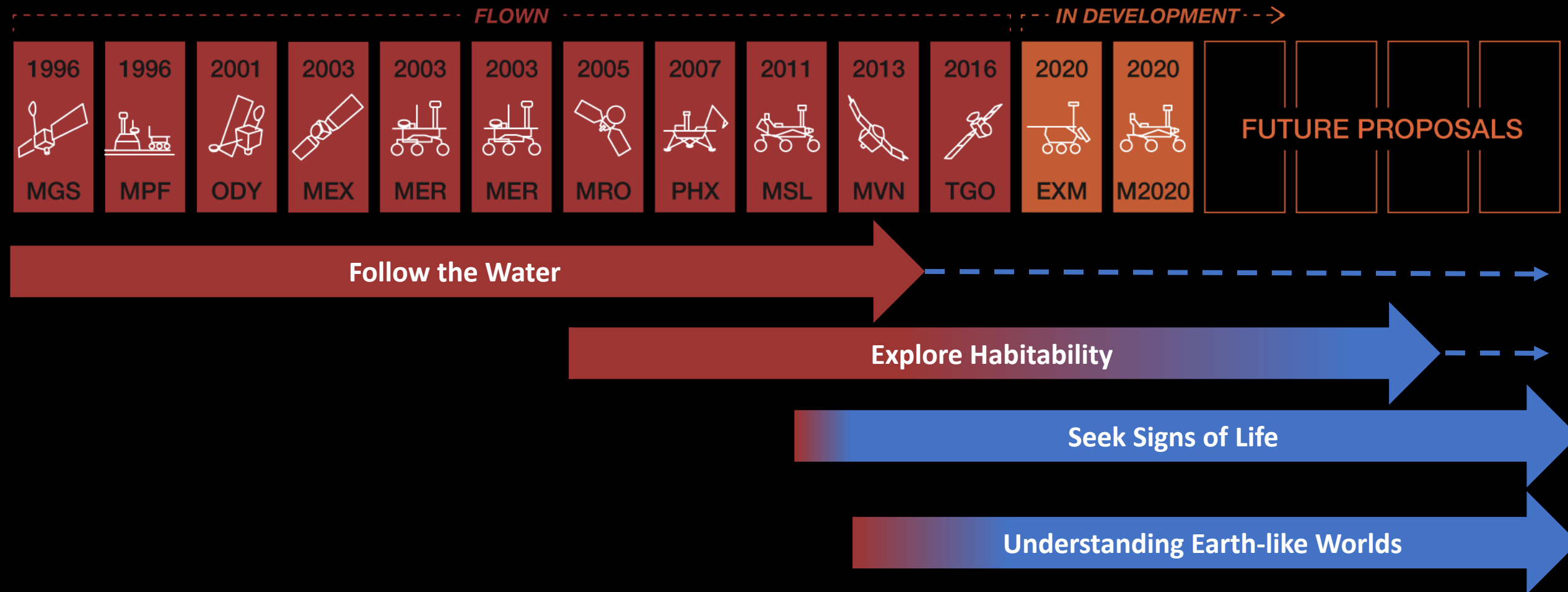
Earth

Mars

Onstott et al., 2019



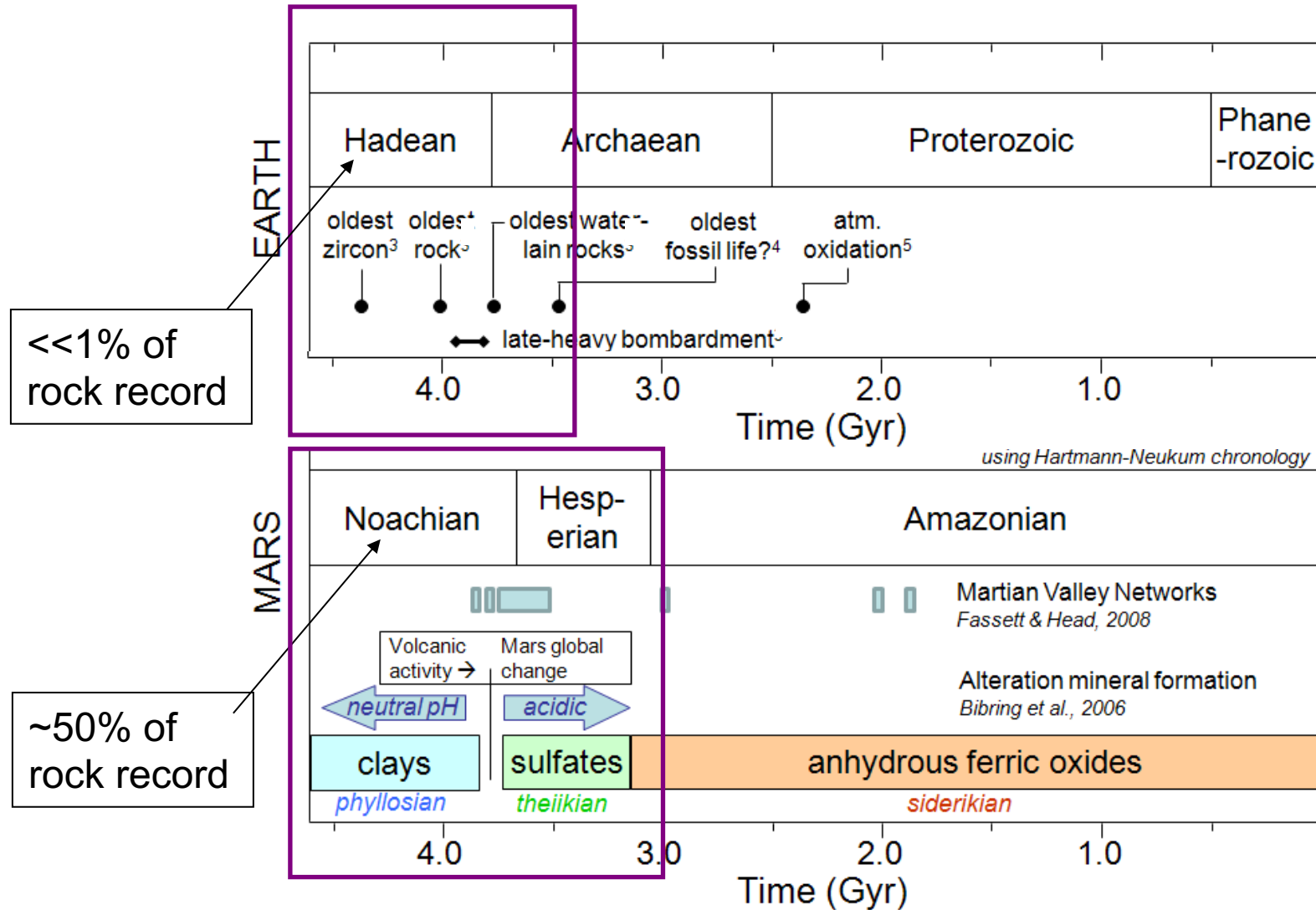
Evolving Science Strategies for Mars Exploration



After Ehlmann et al., 2017, Planetary Science Visions 2050

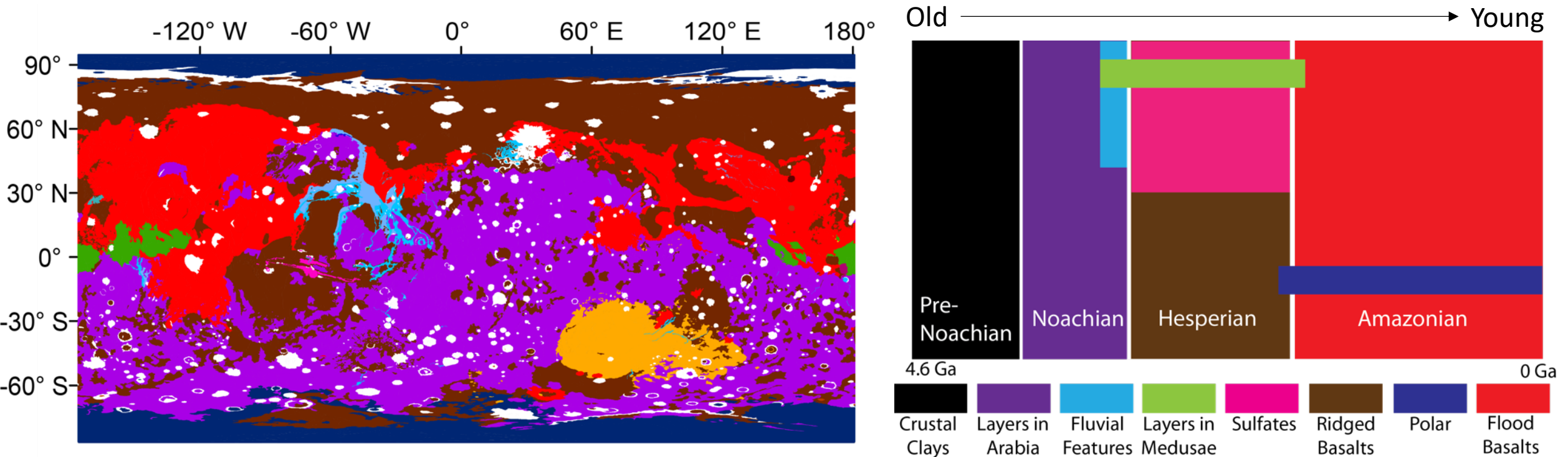
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Understanding Earth-Like Worlds



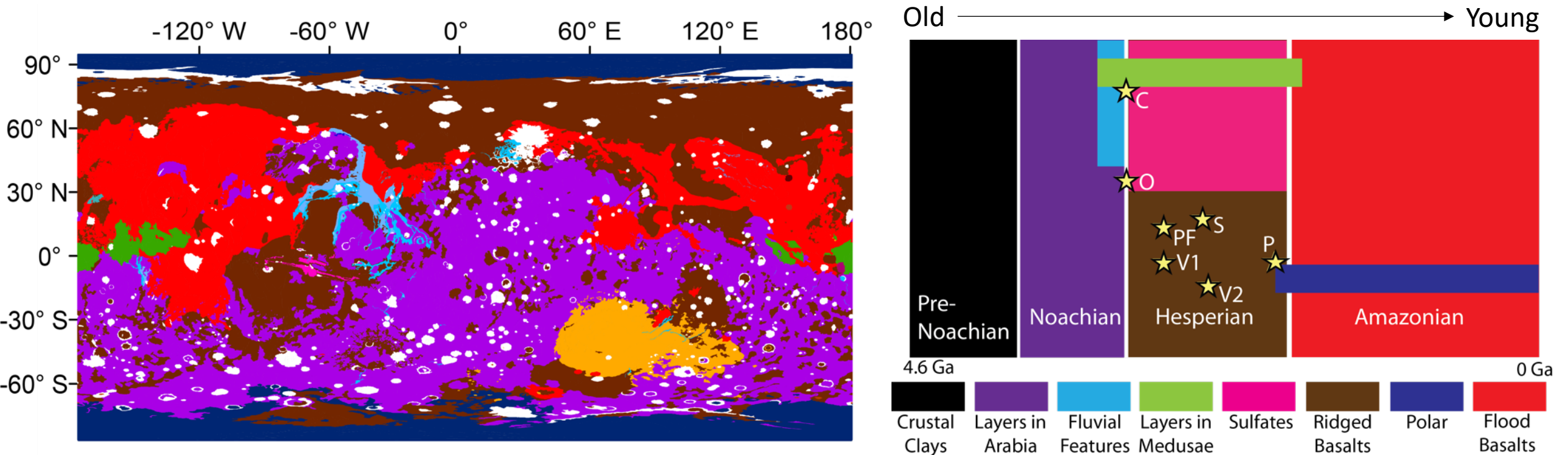
(1) Nyquist et al., 2001 (2) Borg et al., 1999 (3) e.g. Valley et al., 2005 (4) Schopf, 2006 (5) e.g. Farquhar et al., 2000

Sampling of the Martian surface from landed missions is heavily biased towards one type of terrain



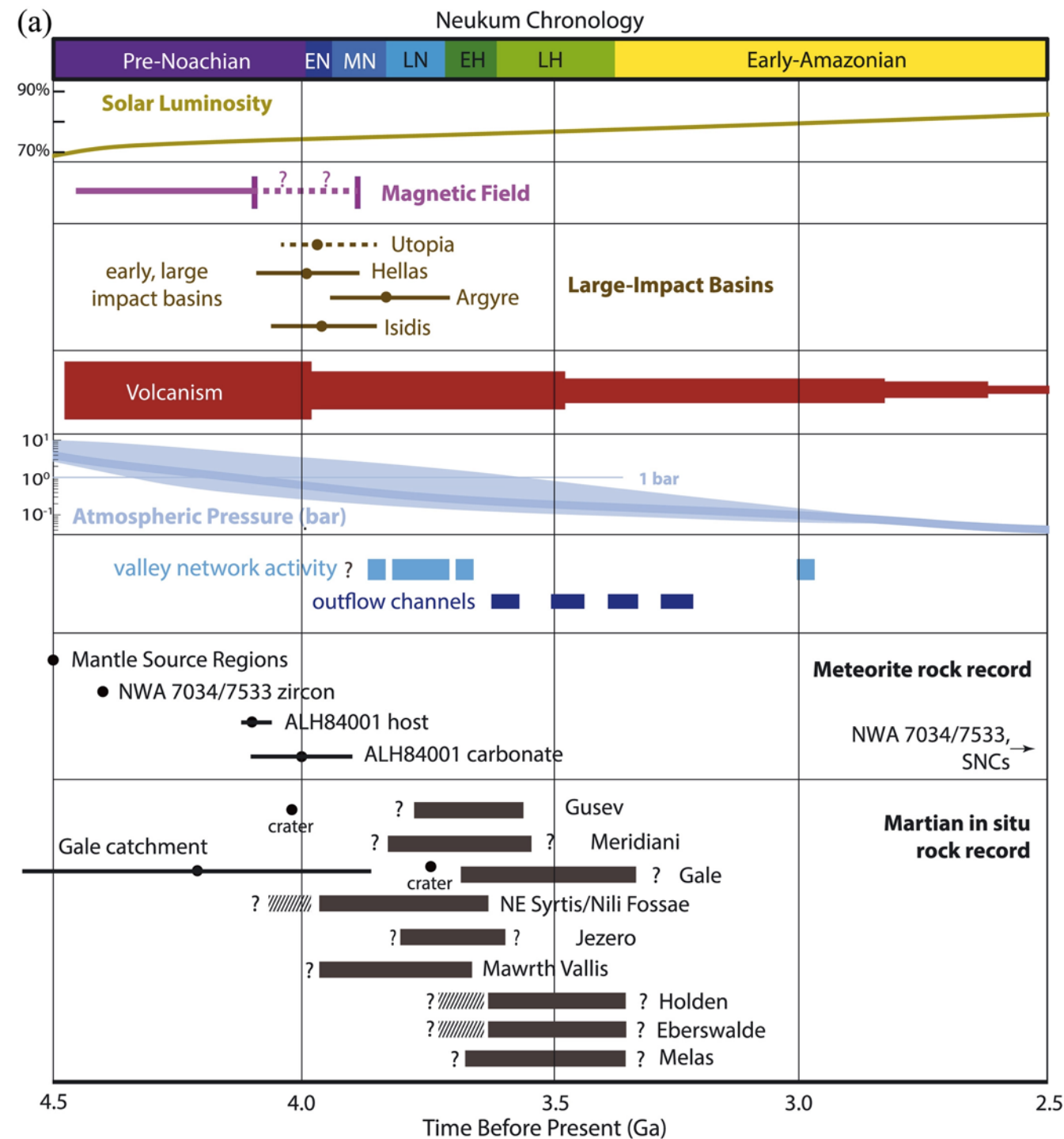
Slide courtesy L. Kerber & K. Stack Morgan

Sampling of the Martian surface from landed missions is heavily biased towards one type of terrain

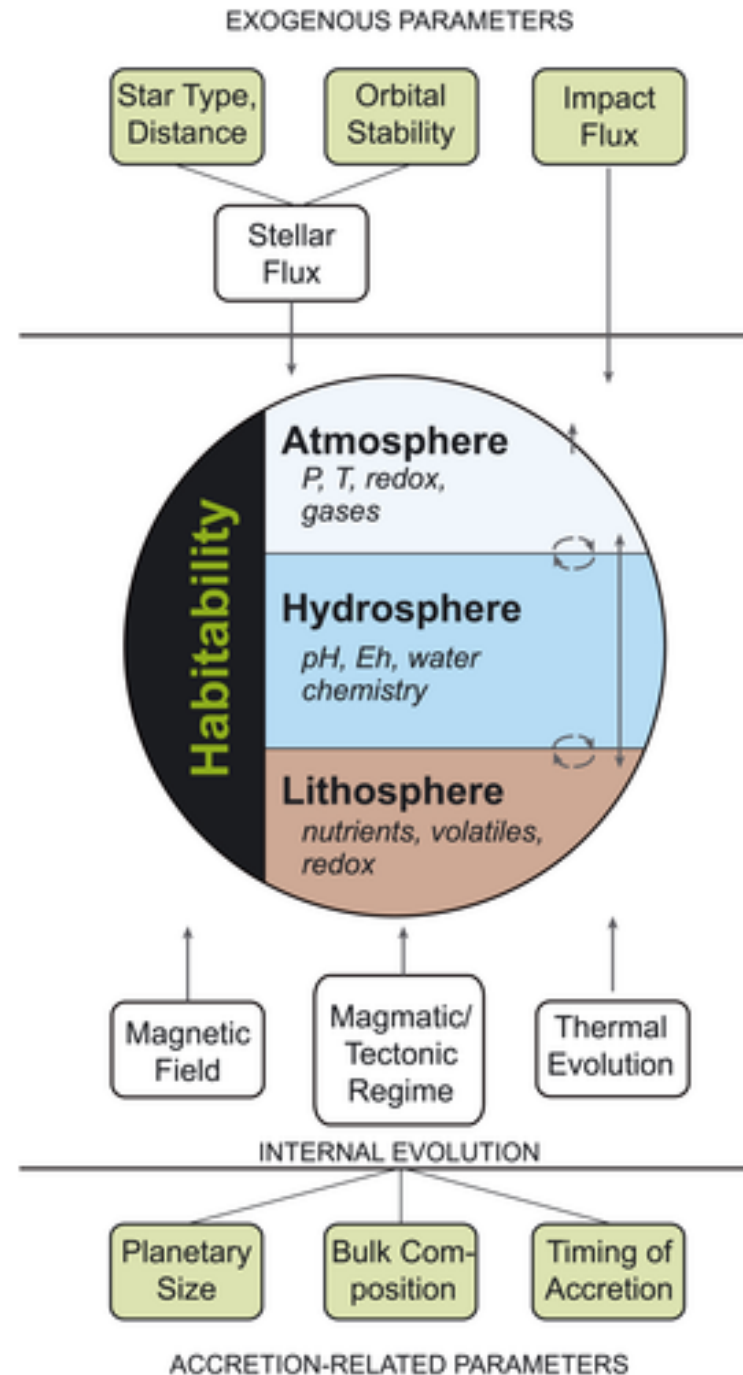


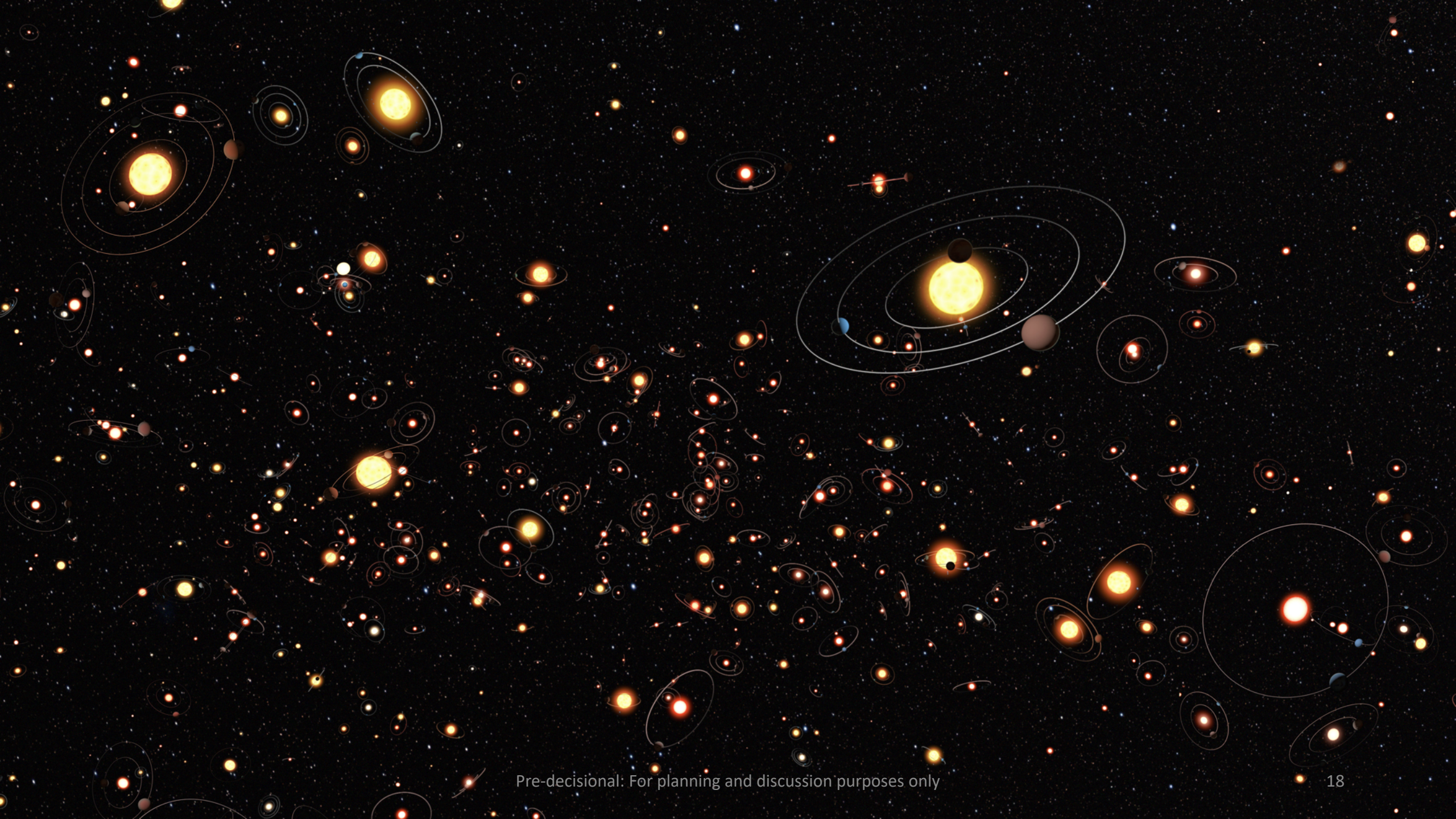
Slide courtesy L. Kerber & K. Stack Morgan

Evidence for
key solar
system
processes
and Martian
evolution are
preserved in
Mars' rock
record

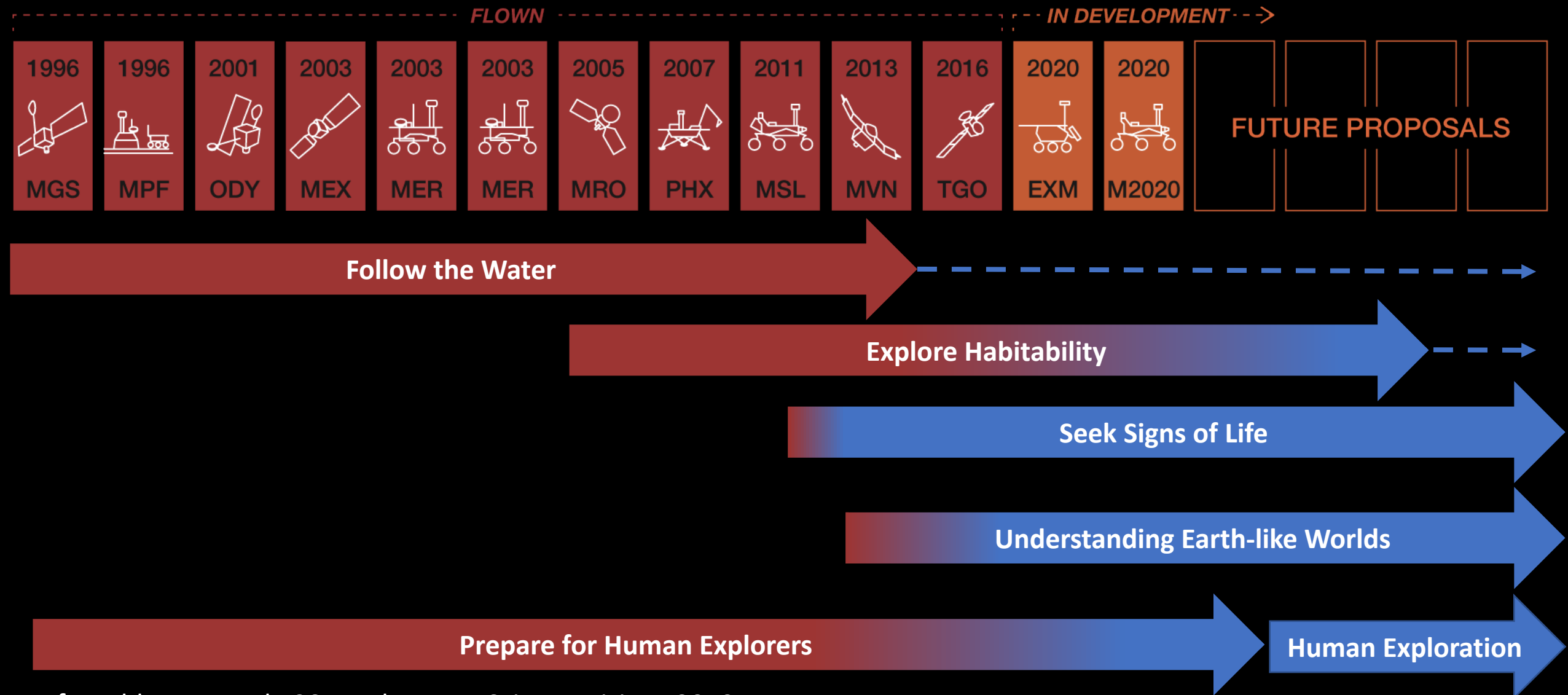


How to these
processes
affect
habitability?
How do rocky
planets
“work”?

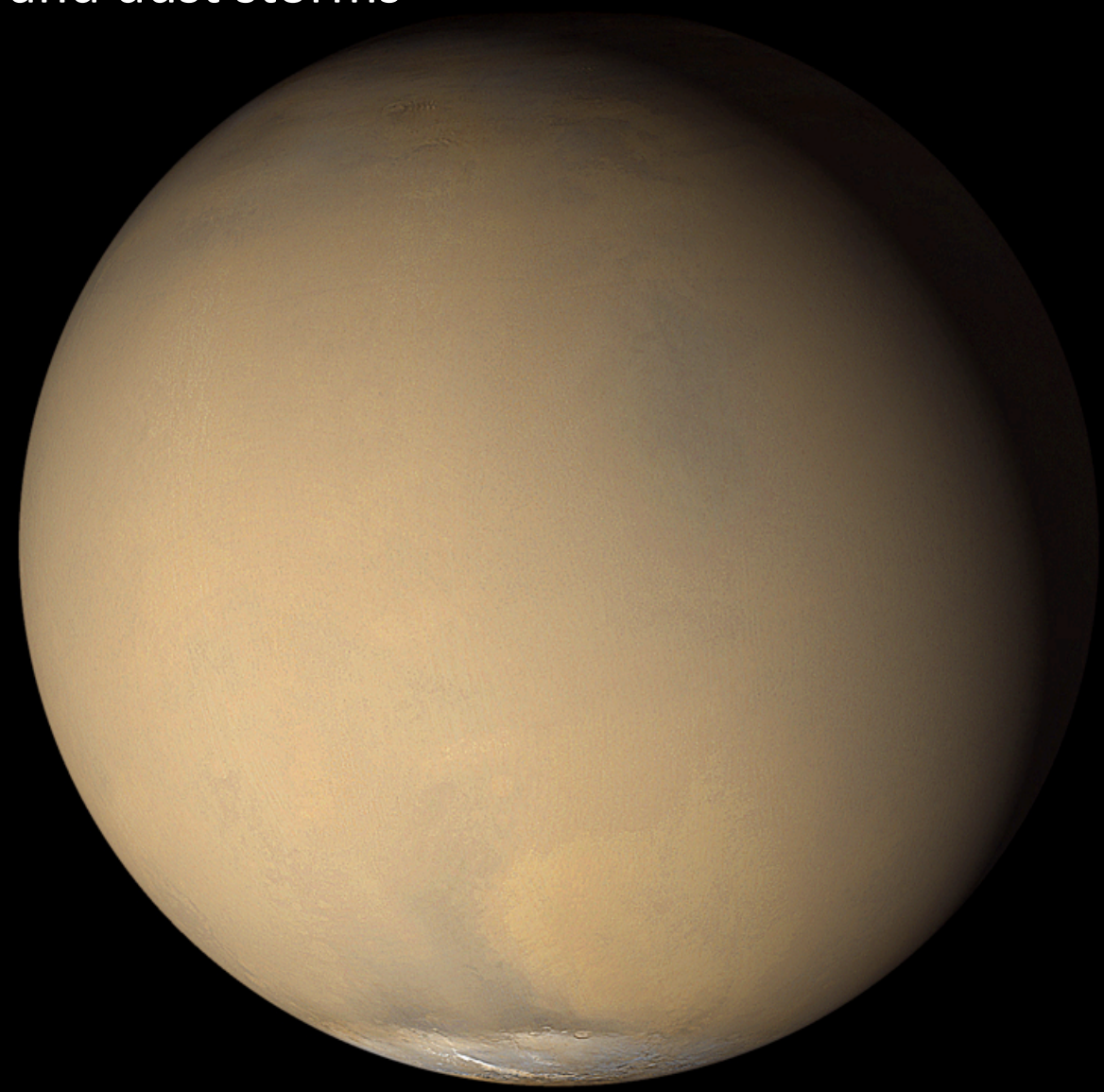
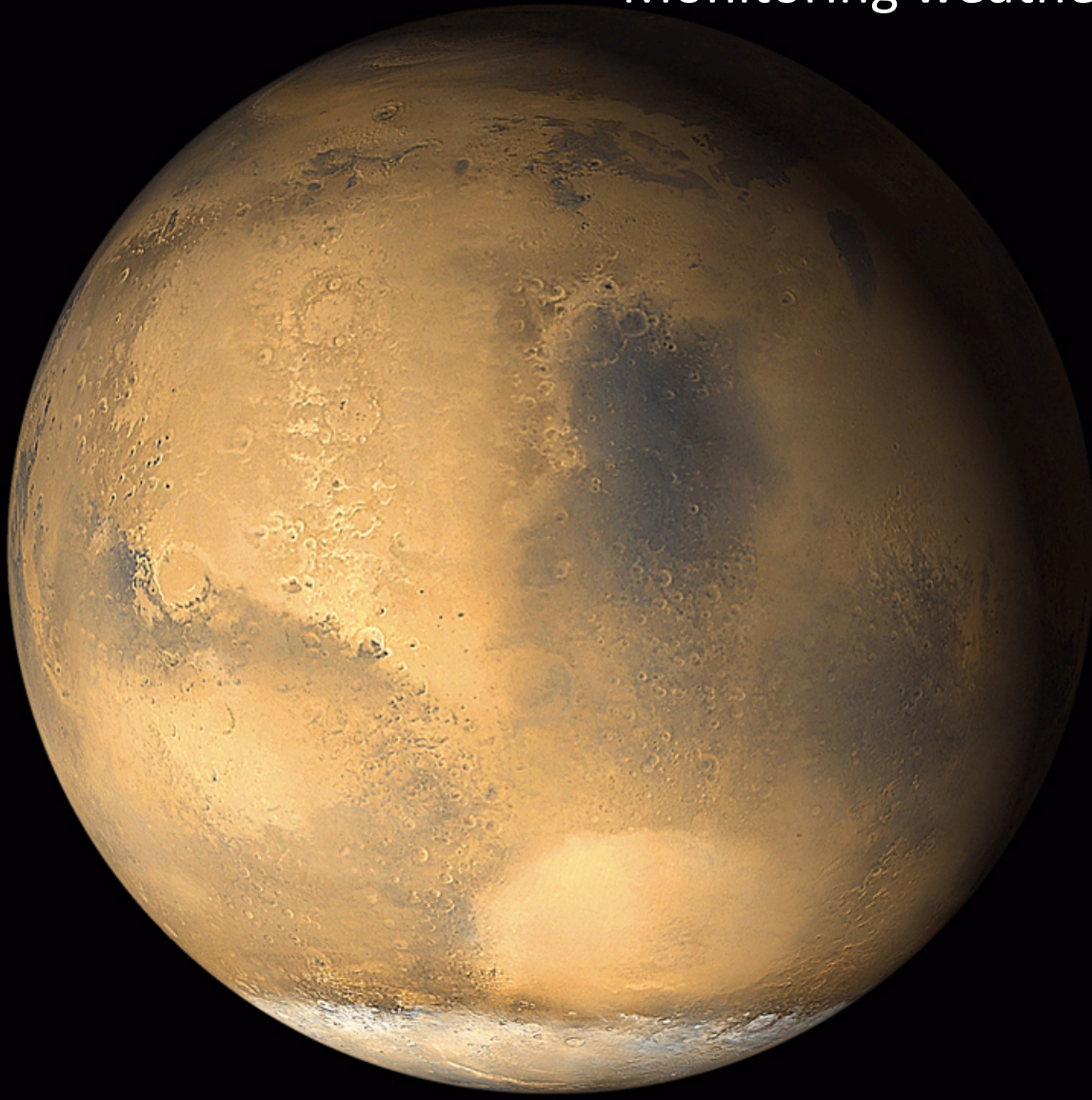




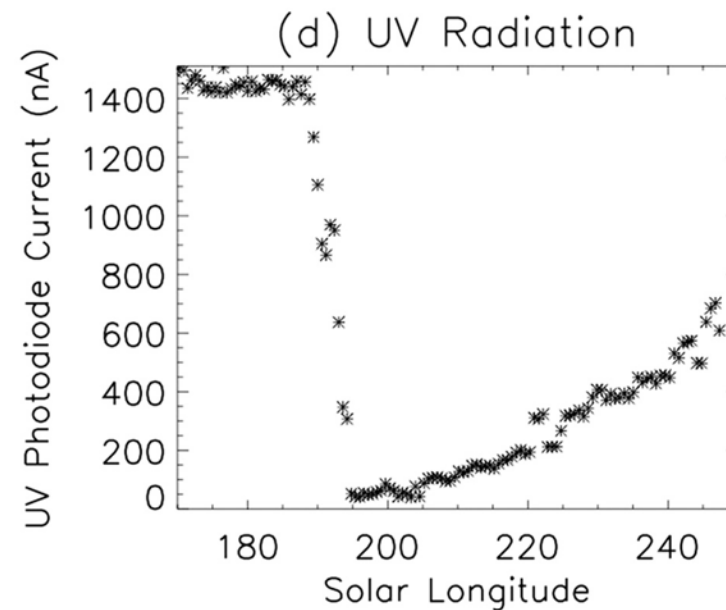
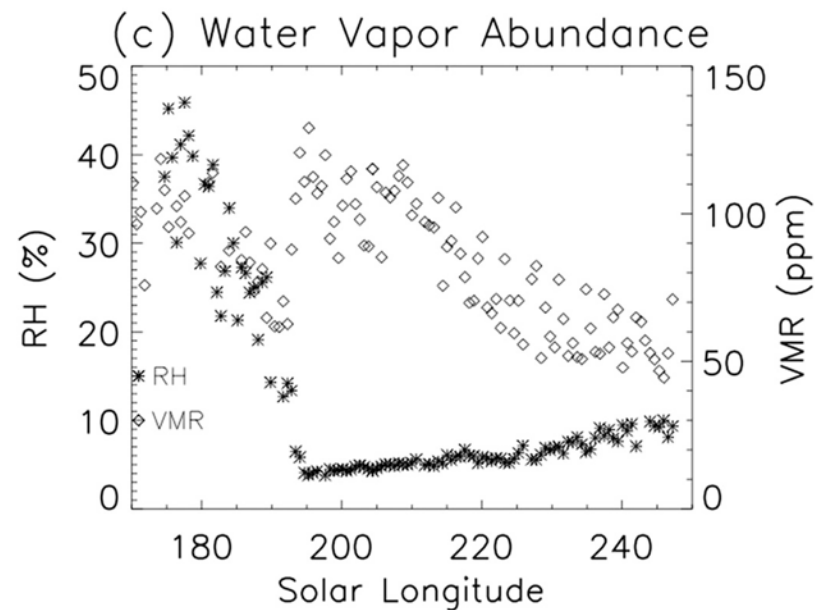
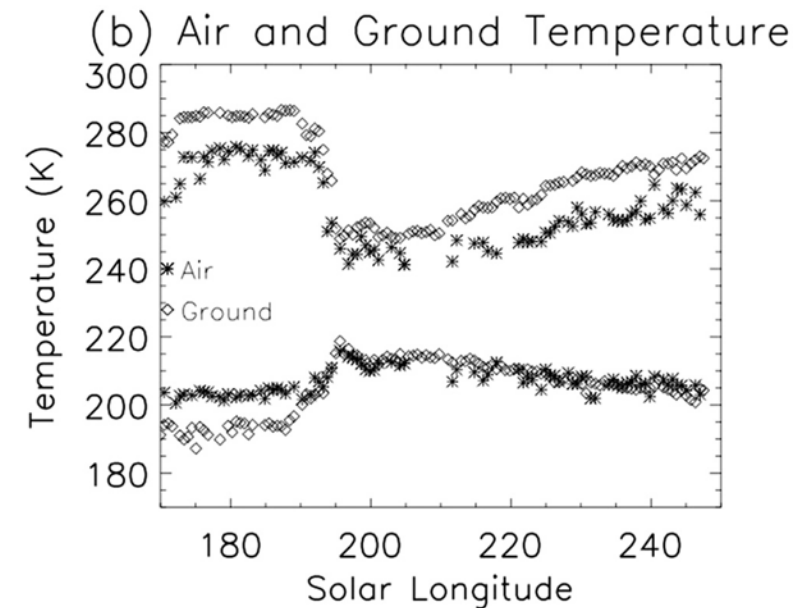
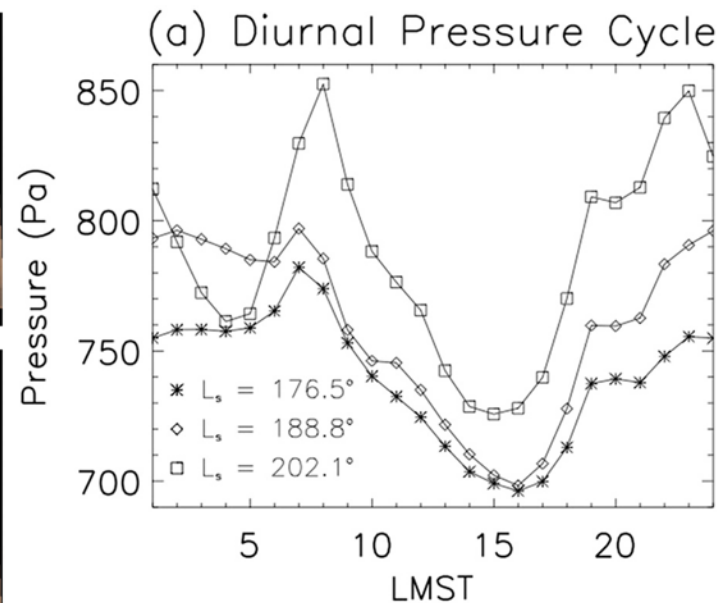
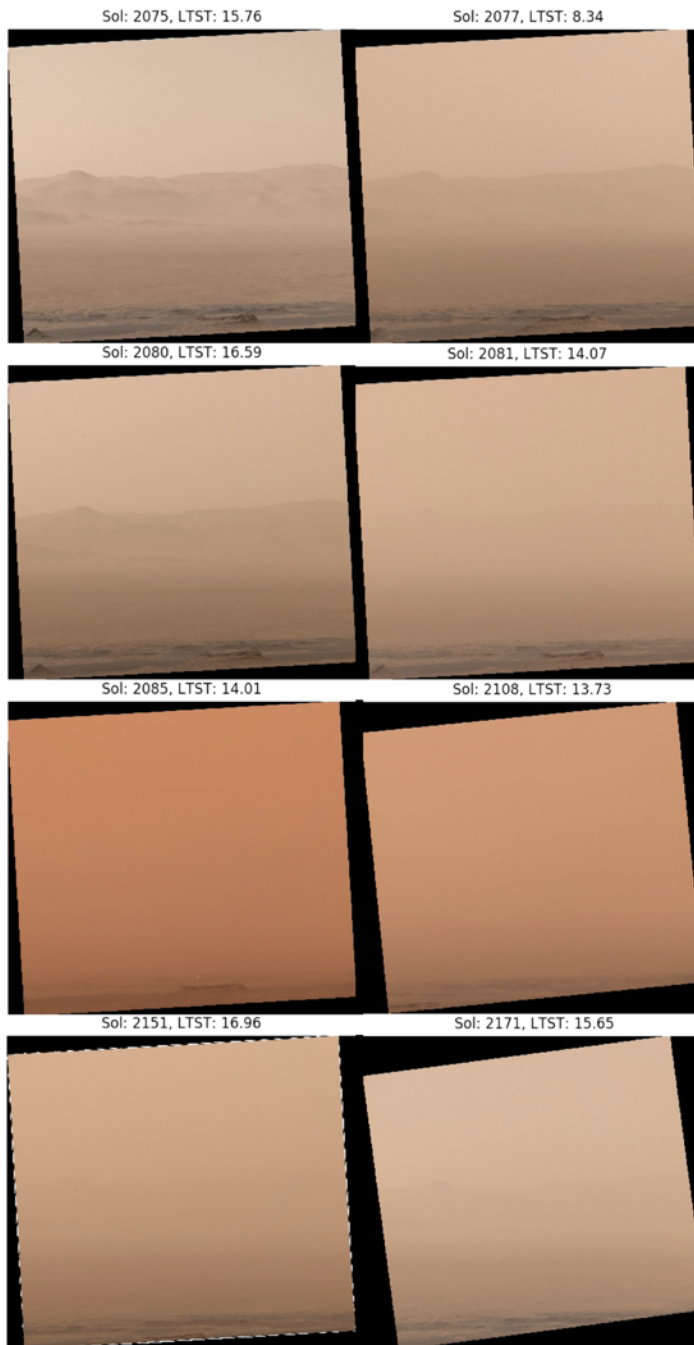
Evolving Science Strategies for Mars Exploration



Monitoring weathering and dust storms

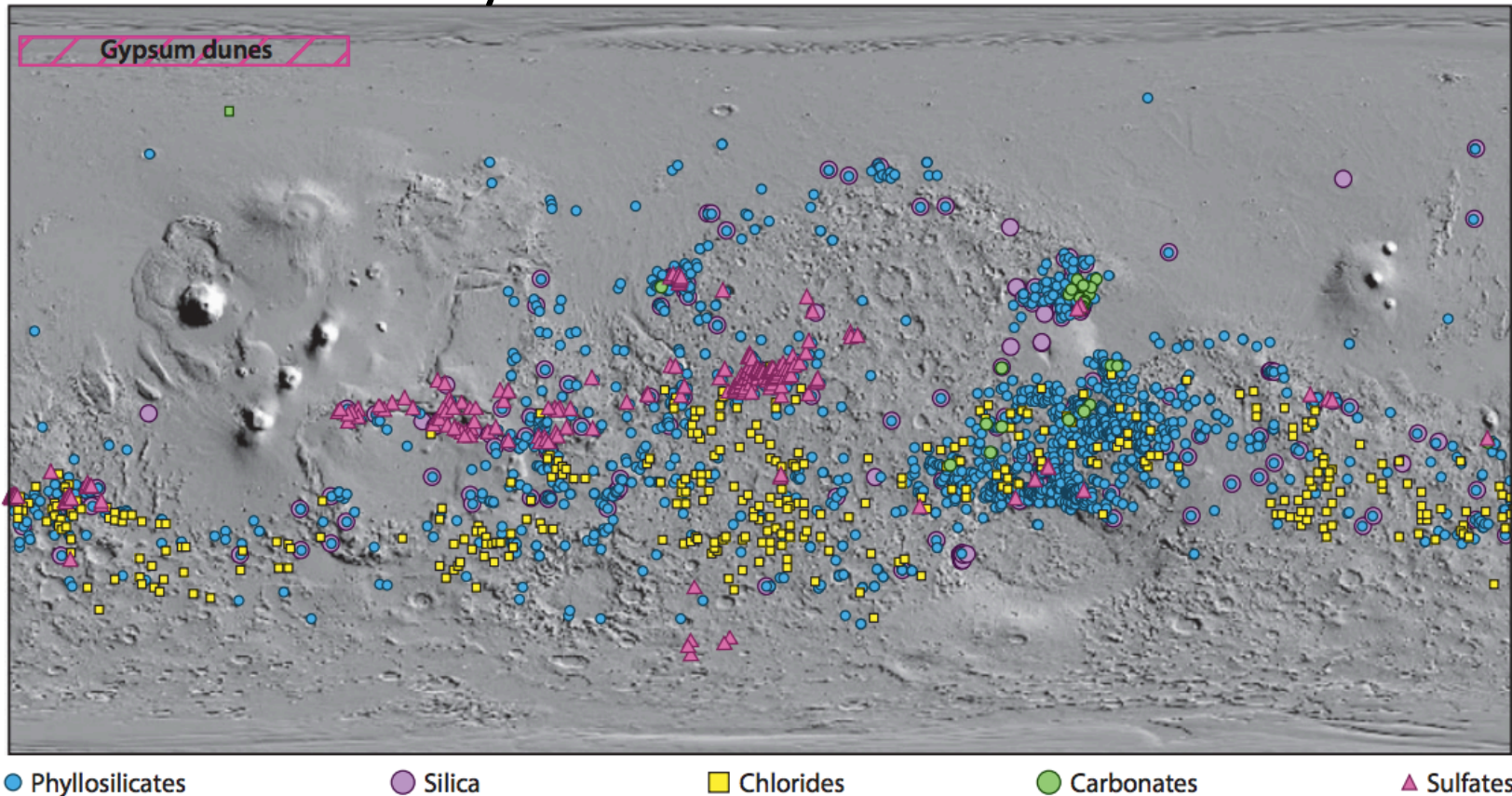


In Situ monitoring of Mars global dust storm from Curiosity



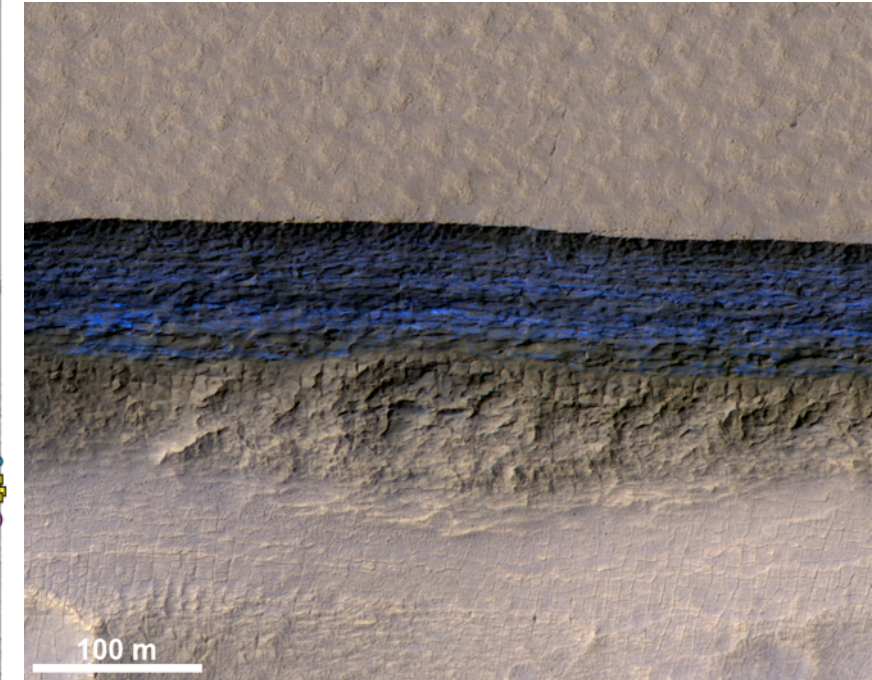
In Situ Resource Utilization

Hydrated Minerals



Ehlmann & Edwards 2015

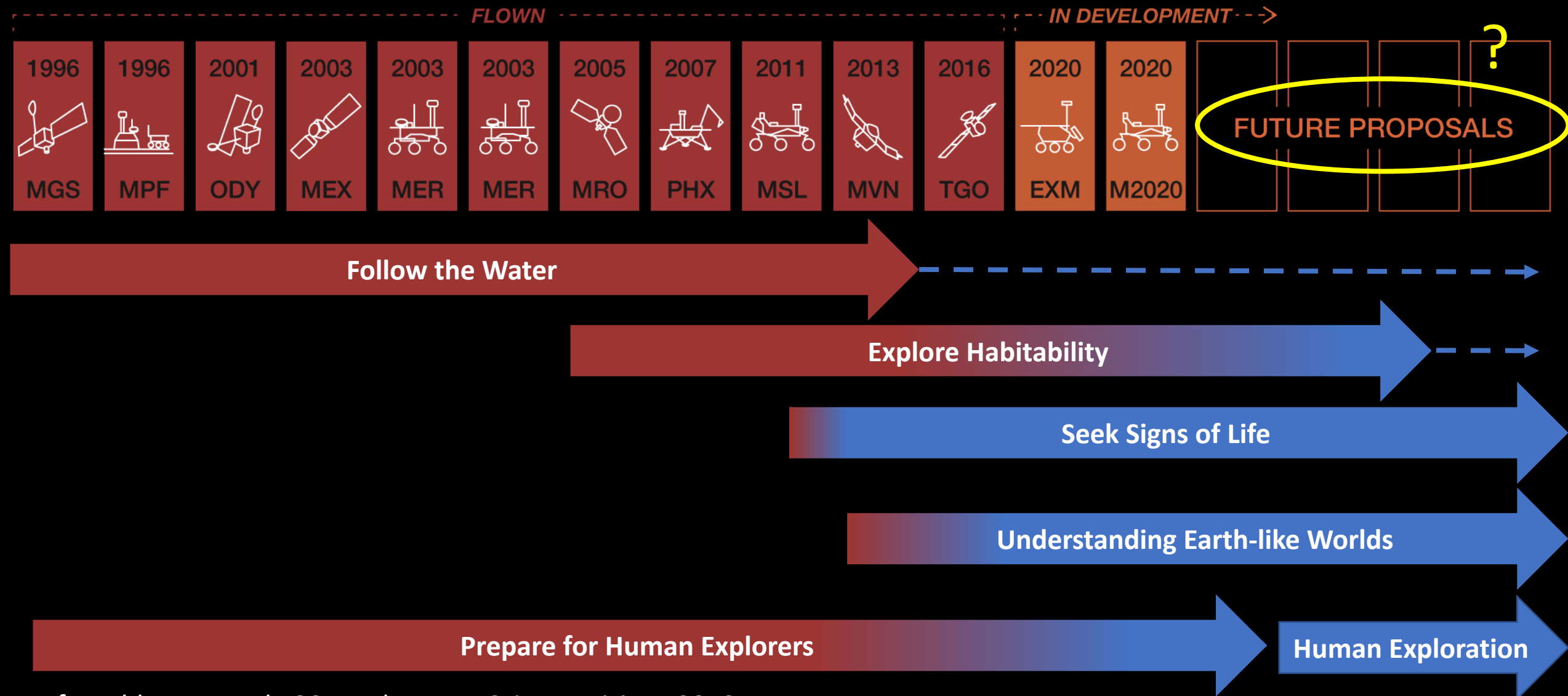
Accessible Water Ice



Dundas et al., 2018

Humans: Where and how much?
Science: How and why?

Evolving Science Strategies for Mars Exploration

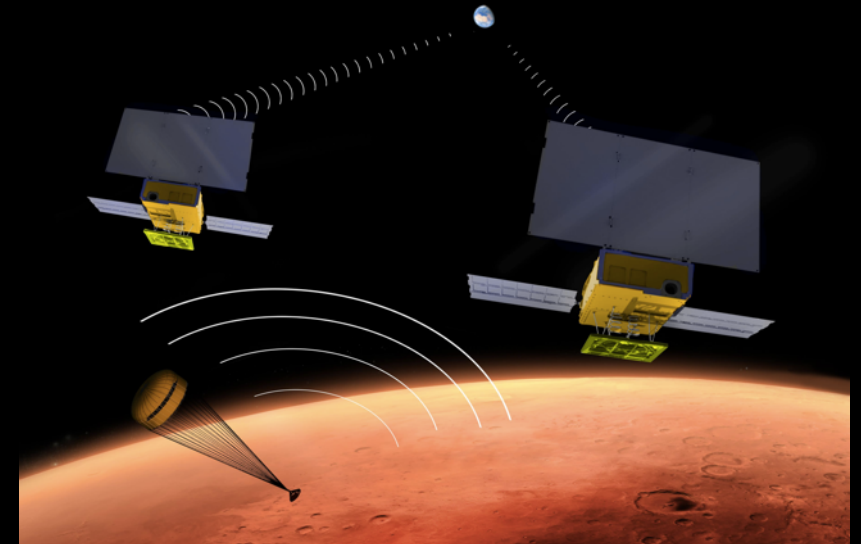
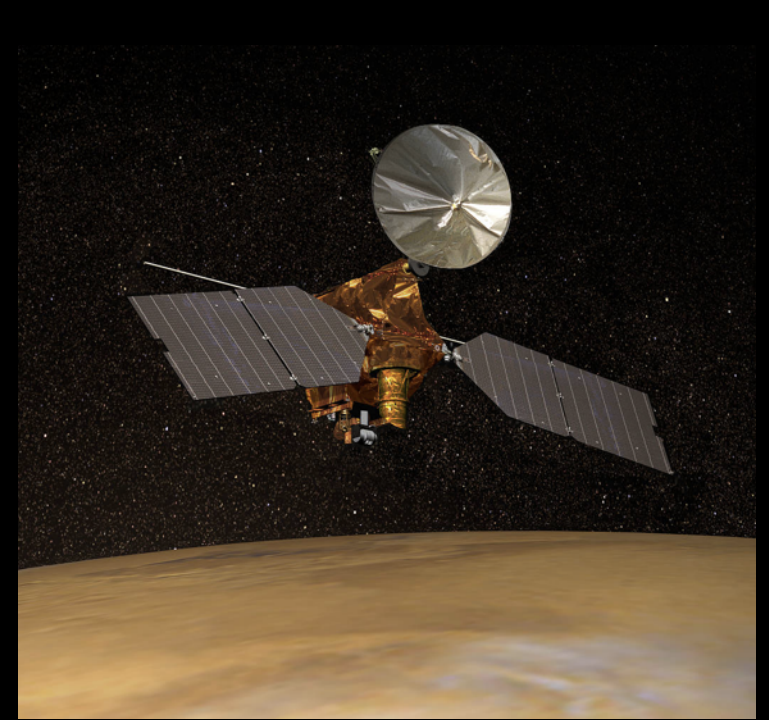


What might future missions look like?

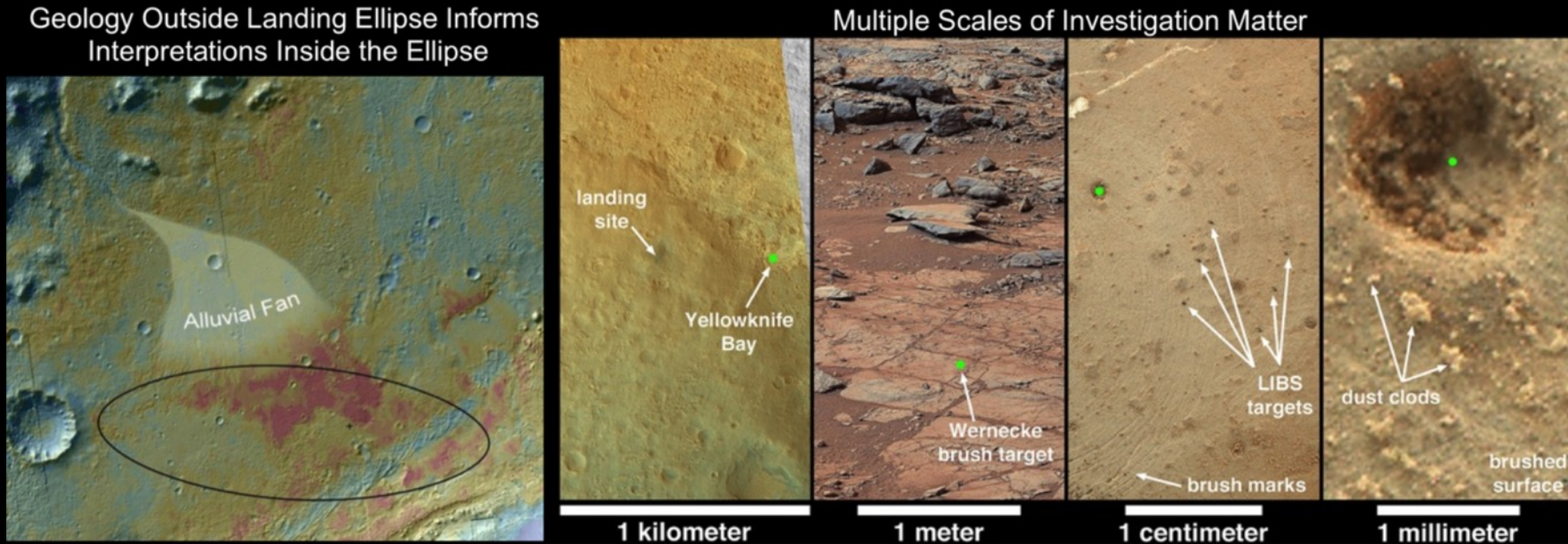
- Mars is diverse, requiring tens of science mission opportunities focused on sites across space/geologic time
- Will requires planning (aka thought-out program) and infrastructure to support
- Simultaneously will need to allow exploration to respond to new discoveries

Orbital Science

- Global coverage, lower resolution than landed missions
- Large orbiters
 - Role in MSR?
 - Resource mappers
 - Monitoring of dynamic modern Mars
- Support surface infrastructure – network of small sats?
 - Global communications/positioning
 - Weather variability (dust storms, winds)



Landed science



- The orders-of-magnitude increase in spatial resolution and analysis capability provided by landed missions vs. orbiters, and the integrated results from key sites across Mars, is needed to address big, system-level questions such as, “What makes Mars, and other terrestrial planets, habitable (or not)?” and “Did life originate on Mars, and if so, how?”
- Mobility also important

Table 3. Necessary Measurements for Understanding the Evolution of Mars Habitability and Their Means of Acquisition: Orbital/Airborne, In Situ, or Sample Return Measurements^a

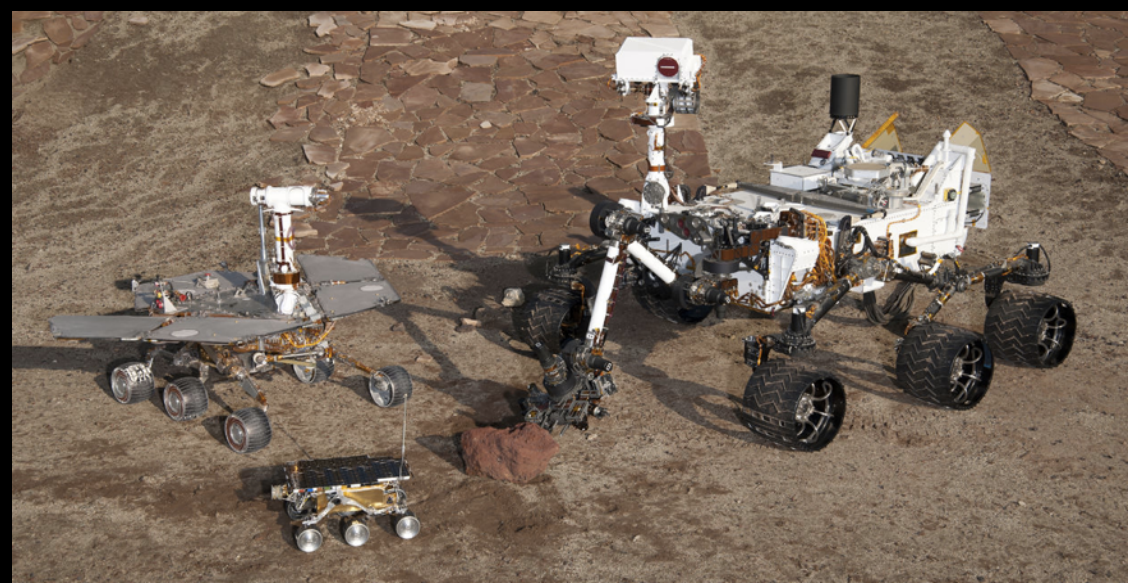
Many high priority science questions require *in situ* (or sample return) measurements

	Orbit/Air		In Situ		Sample Return	
	Pos.?	Req?	Pos.?	Req?	Pos.?	Req?
Stratigraphy and petrology measurements						
Nature of the early Mars rock record, i.e., relative dominance of igneous, impactite, sedimentary units, and record in subcentimeter textures	partial		x		x	
Clay formation environment(s) (weathering, diagenetic, hydrothermal, and metasomatic/deuteric)	partial		x		x	
Identify marker beds in key stratigraphies	partial		x			
Volatile geochemistry, cycling and loss						
H, C, S, N, and O mineral phases in rocks and soils	partial		x		x	
H, C, S, N, and O isotopes in rocks, soils, and ices <i>as a function of time</i> and setting			x		x	
Gas/fluid inclusions in quench melts <i>as a function of time</i>					x	x
Redox indicator minerals and phases, e.g., siderite, Mn phases, and S ₈ , <i>as a function of time</i>			partial		x	
Multiple S and O isotopes for redox <i>as a function of time</i>					x	x
Clumped isotopes for water temperatures <i>as a function of time</i> and setting					x	x
Age date polar caps to understand role of orbital forcing in climate (possibly via ash layers)			x		x	
Paleopressure from vesicles			x		x	
Time-varying high-resolution gravity (seasonal mass flux for ice and water)	x	x				
Timing and effects of key processes						
<i>Timing and duration of heavy bombardment</i> from basin ages and melt ages	partial		x		x	
<i>Time-pinned</i> correlative stratigraphy distinguish local from global trends (age dating and marker beds)	partial		partial		x	
Environmental effects of large volcanic eruptions and large impacts <i>via age dating</i> of volcanic/impactite rocks (and cross correlation with stratigraphies)			x		x	
Recognition of unconformities to understand environmental (dis)continuity	partial		x	x		
Timing and duration of valley networks from cross-cutting relationships <i>and age dating</i>			x		x	
Geophysical evolution						
Magnetic field anomaly locations	x		x			
Magnetic field strength <i>as a function of time</i>			partial		x	
Igneous mineral geochemistry for mantle temperature <i>as a function of time</i>			x		x	
Igneous geochemistry mantle redox state via minor and trace elements, e.g., V/Sc, Cr <i>as a function of time</i>					x	x
REE to understand magma ocean and differentiation evolution					x	x
Interior structure from seismology			x	x		
Spatially distributed heat flux			x	x		

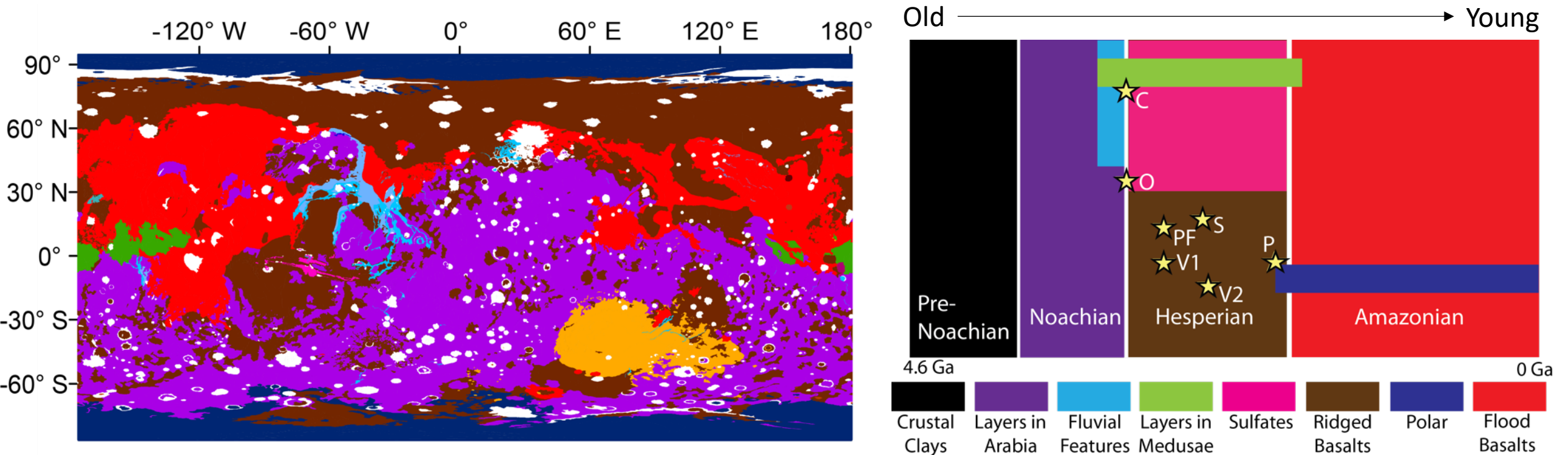
^aWhen measurements must be time-pinned samples, italics indicate the need for age dates. "Pos.?" means the measurement is possible from the given type of platform and "Req.?" means it must be made from that platform.

Landed science

- Can we send some number of identical mobile platforms to the Mars surface over the course of a ~decade?
- Each platform investigate a scientifically important site identified covering a range of terrain ages, spatial locations, and geologic settings.
- The platforms would carry a relatively simple (MER-like) science payload that consists of instruments capable of measuring chemistry, mineralogy, textures, and, if possible, bulk isotopes
- This science payload would be standardized across all vehicles, with the option to swap in specialized instruments specific sites

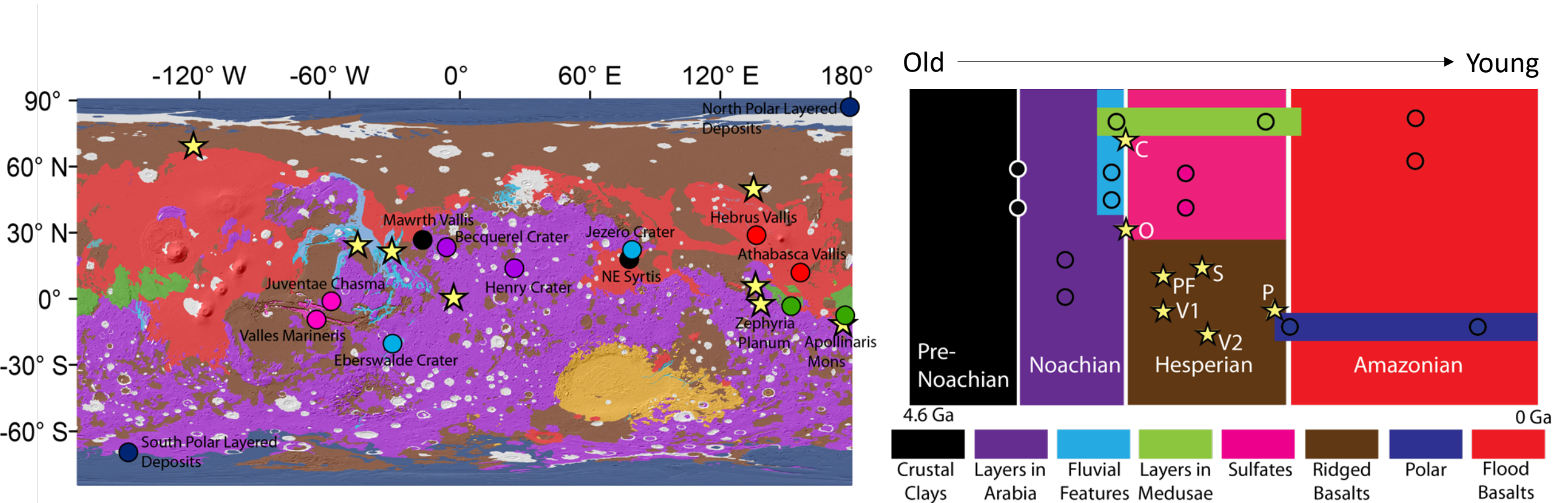


Sample across space, time, environments



Slide courtesy L. Kerber & K. Stack Morgan

Sample across space, time, environments



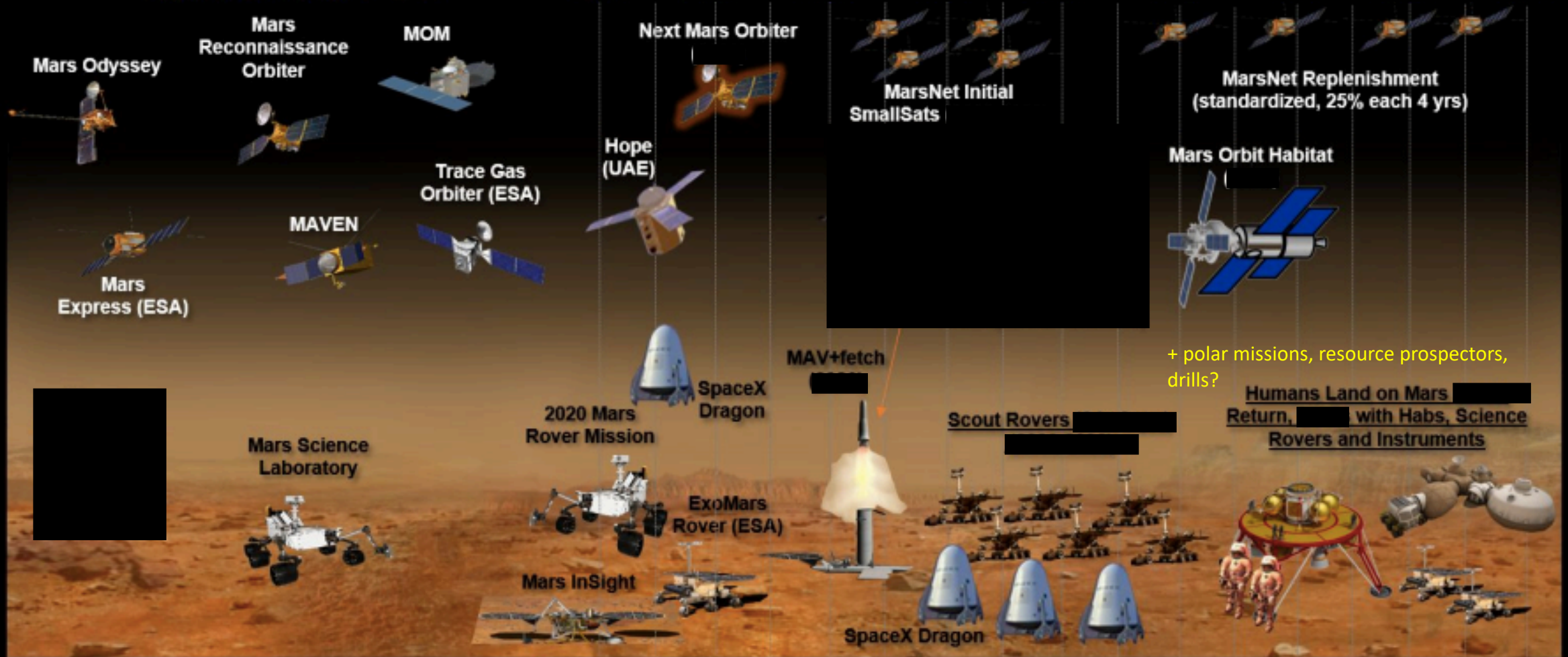
Slide courtesy L. Kerber & K. Stack Morgan

Enabling Affordable Access to the Surface

- Many landed missions = \$\$\$
- Where should/can the innovations occur to make this affordable:
 - Earth to Mars transport
 - EDL options
 - Surface asset size and complexity
 - Reducing the cost of repeat builds
 - Improved operational efficiency

Active Missions 2001 - 2017

2018



+ polar missions, resource prospectors, drills?

Humans Land on Mars
Return, with Habs, Science Rovers and Instruments

Follow the Water

Explore Habitability

Understanding Earth-like Worlds

Seek Signs of Life

Prepare for Human Explorers

Human Exploration of Mars

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